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# RESEARCH MEMORANDUM

FLIGHT TESTS OF A 0.4-SCALE MODEL OF A STAND-ON

TYPE OF VERTICALLY RISING AIRCRAFT

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# FLIGHT TESTS OF A 0.4-SCALE MODEL OF A STAND-ON TYPE OF VERTICALLY RISING AIRCRAFT

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## SUMMARY

An experimental investigation has been conducted to determine the dynamic stability and control characteristics of a 0.4-scale, remotely controlled flying model of a stand-on type of vertically rising aircraft. The aircraft component of the model consisted of a motor-driven, single-rotation propeller in a short shroud with antitorque vanes and control surfaces at the rear of the shroud. A man standing on the machine was represented by a scaled dummy. The investigation covered take-offs and landings, hovering flight, and forward flight at speeds up to a value which represented 80 miles per hour for a full-scale machine. The results of these tests indicated that an aircraft of this type seems feasible from the standpoint of stability and control and can be flown fairly easily in all of these flight conditions.

## INTRODUCTION

There has been considerable interest, particularly on the part of the armed services, in small light-weight vertically rising aircraft for carrying one man and a small amount of equipment. Most of the work done to date has been directed toward the development of small helicopters. An interesting new approach, which was suggested some time ago by Charles H. Zimmerman of the Langley Laboratory, is one in which the man stands on the machine, which has no controls except for torque control, and controls it by tilting the entire machine with his feet. This idea for control which makes use of the natural balancing reactions of the feet has been checked out in hovering flight as reported in reference 1 with a research setup in which a man stood on a platform attached to the nozzle of a compressed-air jet which supplied enough thrust for hovering flight. An aircraft of this type need not necessarily be powered by a small high-velocity jet but might, for example, be powered by a rotor, a shrouded propeller, or a small turbojet. Any of these latter devices might be considered practical from the standpoint of fuel consumption, and consequently, endurance and range.

As a preliminary step in a study proposed for a man-carrying, motor-driven, shrouded-propeller machine, an approximately 0.4-scale remotely controlled model of the research vehicle has been built and flight tested by the Langley Free-Flight Tunnel Section. These tests were conducted between October 29, 1953 and December 4, 1953. The model consisted primarily of a 14-inch-diameter propeller in a shroud 6 inches long with anti-torque vanes and control flaps at the rear of the shroud and with a scaled dummy man mounted in the pilot's location on top of the vehicle. The main purpose of the tests of this model was to obtain some preliminary information on the stability and control characteristics of this type of machine. The flight tests covered take-offs and landings and hovering and forward flight. In all of these tests, the model was controlled by means of the control surfaces at the rear of the shroud.

## NOMENCLATURE AND SYMBOLS

Since the model represents a very unusual type of aircraft, it is desirable to establish the meaning of a few ordinary terms as they will be used in this paper to describe the model or its motions. The flight pattern of the stand-on type aircraft is similar to that of the tail-sitter type of vertically rising airplane in that both take-off vertically and then the whole machine is tilted to produce forward thrust for forward flight. The same system of nomenclature is therefore used in discussing the stand-on aircraft as has previously been used in discussing the tail-sitter type of vertically rising airplane. That is, the machine is considered as a conventional airplane that takes off, lands, and hovers in a tail-down attitude and the motions are referred to with respect to a body system of axes. Angular motion about the propeller shaft (or pilot's body) axis is referred to as roll, angular motion about a transverse axis which extends sideways relative to the pilot is referred to as pitch, and angular motion about a transverse axis which extends fore and aft relative to the pilot is referred to as yaw. The flight records shown in the present paper are presented directly as they were read from the motion-picture records of the tests. That is, they have not been corrected from the plane shown by the camera to a consistent series of axes referred to the model on the earth. For this reason, it is difficult to show the axes on a sketch, and consequently, no sketch of the axes, such as is normally used in defining the symbols, is used to supplement the following definitions:

V tunnel airspeed in forward flight tests

T thrust of model

L rolling moment about propeller shaft axis

y sidewise displacement in a horizontal plane, positive for displacement to right

$h$ height of lowest landing gear above ground

$t$ time

$\tau$ angle of tilt of propeller shaft axis from the vertical, positive for forward tilt

$\psi$ angle of yaw, positive for right yaw; for hovering flight $\psi$ is measured from the vertical - for forward flight it is measured from the vertical in the plane shown by the rear camera

$\delta_e$ simultaneous up or down deflection of elevons

$\delta_a$ differential deflection of elevons

$\delta_r$ rudder deflection

## APPARATUS AND TESTS

### Model

Photographs and sketches of the model are presented in figures 1 and 2. As pointed out in the introduction, it was approximately a 0.4-scale model of a proposed man-carrying research vehicle. The model had a 14-inch-diameter, fixed-pitch propeller driven by a 5-horsepower electric motor in a shroud 6 inches long. The shroud had a round nose which increased the thrust of the propeller-shroud combination as explained in reference 2. In the exit end of the shroud were four antitorque vanes with movable flaps which served as control surfaces. Two of the control surfaces acted somewhat as the elevons of an airplane, that is, they deflected differentially to provide roll (torque) control and deflected together to provide pitch control about one transverse axis of the model. The other two control surfaces deflected only together and provided yaw control about the other transverse axis. Eight additional antitorque vanes that were simply pieces of sheet metal were spaced around the exit end of the shroud and set at a small angle of attack relative to radii of the model to provide an effective means of counteracting the propeller torque when the model was near the ground. The need for these radial antitorque vanes and the reasoning behind them is explained in the section entitled "Results and Discussion." The additional antitorque vanes are referred to in the rest of the paper as the radial antitorque vanes and the four vanes with control surfaces in the rear of the shroud are referred to as the axial antitorque vanes.

A scaled dummy man was mounted on the model but the grating on which he would stand on the full-scale vehicle was left off. The control-actuating mechanisms were located on the "man" and were connected to the

controls by means of flexible push rods in tubular guides. A structure of tubing around the "man" provided an attachment point for the safety cable; the tube behind the "man" served as a track on which the safety-cable attachment could slide from a position over the "man's" head for hovering flight to a point near the center of gravity for forward flight. A similar structure is included in the design of the full-size test vehicle for the same purpose. The tubes of this structure extended past the exit of shroud to serve as a landing gear. No spring or shock-absorbing action was provided by this landing gear. Three types of tips were used on the gear - sharp pointed spikes, hemispherical rubber buttons of about 3/4-inch diameter, and rounded steel buttons.

The control-actuating mechanisms were of the flicker (full on or full off) type used on all models by the Langley Free-Flight Tunnel Section. These mechanisms were equipped with an integrating-type trimmer which trimmed the control a small amount in the direction the control was moved each time a control deflection was applied. With mechanisms of this type, a model becomes accurately trimmed after flying a short time in a given flight condition. The thrust of the model was varied by varying the speed of the motor and propeller.

The weight of the model varied from 23 to 25 pounds during the tests. Insofar as mass and mass distribution are concerned, the model represented approximately a 200-pound man and a 175-pound machine. Preliminary analysis has indicated that such a weight allowance for the machine is reasonable.

## Test Equipment and Setup

The take-off, landing, and hovering tests were conducted in a large building which provides protection from the random effects of outside air currents and thereby permits the basic stability and control characteristics of the model to be determined more readily. The forward flight tests were conducted in the Langley full-scale tunnel.

The test setup used in all the tests was approximately the same. This setup is illustrated for the forward flight tests in figure 3. This sketch shows the pitch pilot, power and safety-cable operators, and a camera on a balcony at the side of the test section. The roll pilot was located in an enclosure in the lower rear part of the test section, and the yaw pilot and a second camera operator were at the top rear of the test section. The three pilots were located at positions which gave them a good vantage point for observing and controlling the particular phase of the motion with which they were concerned. In the hovering tests, which were made in a different facility, the various pilots and operators were also stationed at various positions around the test area to give them a good vantage point for observing and flying the model.

A safety cable was used for catching the model to prevent crashes in case of control failure or in the event that the pilots lost control of the model. This cable was attached to a ring that was free to slide on one member of the tubular safety structure as explained under the description of the model. It ran through a pulley at the ceiling of the test chamber and then to the safety-cable operator who adjusted the cable to keep it slack during the tests or to catch the model at the end of a flight.

The power cable was taped to the safety cable for a distance of about 15 feet above the model and was then led to the power sources. This cable consisted of a flexible plastic tube which provided air for the electro-pneumatic control actuators, and electric cables which supplied power for the motor and carried the remote-control signals to the control actuators.

## Tests

The investigation consisted of flight tests to determine the stability and control characteristics of the model in vertical take-offs and landings in still air, in hovering flight in still air, and in forward flight. The test results were obtained both from the pilots' observations and opinions of the behavior of the model and from motion-picture records of the motions of the model. The control travels from the trim position in all of the tests were approximately:

$$\delta_e = \pm 20^\circ$$

$$\delta_r = \pm 20^\circ$$

$$\delta_a = \pm 60^\circ$$

The take-off tests were made by increasing the power to the model fairly rapidly until it took off. After the take-off, power was reduced until the model stabilized at a height of about 10 feet above the ground.

The landing tests were started with the model in steady hovering flight at a height of about 10 feet above the ground. The power was reduced slightly so that the model descended slowly until the landing gear was about 6 inches above the ground. At this point the power was cut off abruptly and the model dropped to the ground.

The hovering-flight tests were made at a height of 15 to 20 feet above the ground in order to study the basic stability and control characteristics of the model when it was high enough to eliminate any possible

effect of ground proximity. In these tests the ease with which the model could be flown in steady hovering flight and maneuvered from one position to another was studied. The stability of the motions about the transverse axes was also investigated by observing the uncontrolled yawing motions that developed after the model had been settled down into a steady hovering flight condition in as accurate trim as possible. In these tests the model was controlled by the pilots in pitch and roll in order that the stability of the yawing motions could be studied more carefully. Only the yawing motions were studied in detail because, for reasons of symmetry, the pitching motions would be expected to be almost exactly the same as the yawing motions. The ability of the pilot to stop these uncontrolled motions by the use of the controls after the motions had been allowed to build up to a fairly large amplitude was also studied.

The forward-flight tests were made by starting with the model hovering in the test section of the tunnel at zero airspeed. The tunnel was then turned on at its idling-speed setting and the model was tilted progressively farther into the wind to hold its fore-and-aft position in the test section as the airspeed increased. After the airspeed had come up approximately to the idling speed (25 miles per hour), the speed was slowly increased to about 50 miles per hour. Since the tunnel airspeed increased slowly (2 to 3 minutes were required to go from 0 to 50 miles per hour) the model was effectively flown in steady trimmed flight at all airspeeds within this range. The tests were limited to a speed of 50 miles per hour which is approximately the maximum speed of the tunnel in its low-speed range. The forward-flight tests were made without the radial antitorque vanes installed on the model since these tests were made before the take-off tests which showed the need for these vanes. The forward-flight tests were not repeated with the radial antitorque vanes installed because it was believed that these vanes would not have a major effect on the stability and control characteristics of the model in forward flight.

## RESULTS AND DISCUSSION

The motion pictures of flight tests of the model give a much clearer impression of the problem of flying a stand-on type of vertically rising aircraft than is possible in this printed presentation. A motion-picture film supplement to this paper has therefore been prepared and is available on loan from the NACA Headquarters, Washington, D. C.

### Hovering Flight

The model could be flown smoothly and fairly easily in hovering flight and could be maneuvered to any desired position at will. This result is illustrated in figure 4 which presents a time history of a

test in which the flight plan was for the pilot to fly the model steadily in one position for a while and then to move it to another position where he would fly it steadily before going on to another position. The figure and the film supplement show that the pilot could fly the model reasonably steadily in one position and that he could move it fairly rapidly to another position and restore it to a reasonably steady flight condition quickly.

The model seemed about neutrally stable in yaw and pitch. Since preliminary flight tests showed that the stability in yaw and pitch were almost exactly the same, as would be expected because of the symmetry of the model, only the yawing motions were studied in detail. Time histories of the uncontrolled yawing motions are presented in figure 5. In these flights the pilot allowed the model to fly uncontrolled as long as possible within the limits allowed by the safety, power, and control cable before he started applying corrective control to stop the motion. The data of figure 5 show that in some cases the model seemed to have a slightly unstable oscillation whereas in other cases it diverged aperiodically as though it were slightly unstable or slightly out of trim. When a model is about neutrally stable, indefinite results such as these are obtained because of the small inconsistent forces exerted by the safety, power, and control cable, and because of slight out-of-trim control moments.

The uncontrolled-flight records shown in figure 5 and in the film supplement were obtained with the safety cable and air line coming in to the model from above and attached to the top of the tubular safety structure and with the electric lines for the motor and control actuators attached to the rear of the motor housing and trailing downward to the ground. This special setup was made for these tests because preliminary tests showed that an overhead cable alone made the model develop an unstable oscillation whereas a trailing cable alone made the model diverge aperiodically. This cable effect, which is of little importance for most vertically rising aircraft models, was more important in the present case because the cable was larger with respect to the model and because the model was so nearly neutrally stable that differences in the cable setup could cause differences in the type of uncontrolled motion that was obtained. The divided cable setup finally used in obtaining the results presented in figure 5 and in the film supplement minimized the effect of the cable.

The ability of the pilot to stop the uncontrolled motions even after they had been allowed to build up to a fairly large amplitude is also illustrated in figure 5. Here, as in figure 4, it is evident that the pilot was able to stop fairly rapid motions of the model reasonably quickly by use of the controls. The pilot felt, however, that the yaw and pitch controls were somewhat weaker than is desirable for rapid maneuvering. He was able to stop rapid motions about as quickly as with

vertically rising airplane models which have been flown in the past, but he had to hold the controls on longer and generally exercise more skill than was required with the other models. This result, of course, applies only for the case of control by means of surfaces at the rear of the shroud. For an aircraft of this type in which the pilot stood and used the natural balancing reactions of his feet for control, as was the case in reference 1, the type of control would be so different that the controllability results from the present investigation cannot be applied except in the most general way.

The rolling motions, as would be expected, seemed neutrally stable and were very easy to control. The vertical motions were also easy to control. The model would be expected to have damping of the vertical motions because of the inverse variation of thrust with upward velocity. Because of this damping and the fact that varying the motor speed provided sufficiently rapid changes in thrust, the model could be flown steadily at any desired height.

## Take-Offs

Take-offs could be made very easily; in fact, they were easier to perform than for any vertically rising aircraft model previously tested. The time histories of figure 6 show that the model took off vertically with very little control required. For all of these take-offs, the controls were trimmed for hovering flight before the start of the tests as has always been the case in take-off tests of vertically rising aircraft models.

Some earlier take-off tests made without the eight antitorque vanes around the outside of the shroud showed the need for these vanes or some similar device. Without these vanes the model would roll two or more complete revolutions during a take-off depending on the vertical speed of the take-off. This result was not unexpected since force tests made previously on a generally similar model had shown that an out-of-trim torque developed as the model neared the ground. The results of these force tests are shown in figure 7. This figure shows that for the control setting used in the tests the model was approximately in trim in roll for hovering flight well above the ground and that a large out-of-trim rolling moment developed as the height above the ground decreased. When the model was very close to the ground this out-of-trim rolling moment was approximately equal to the motor torque. Apparently, as the trailing edge of the shroud nears the ground, the air has an increasingly difficult time getting out of the shroud because of the reduction in the area through which the air can leave the shroud. The flow through the shroud is therefore reduced and the axial antitorque vanes in the shroud lose their effectiveness. Some special antitorque device that will come into play as the model nears the ground is therefore needed.

The radial antitorque vanes around the outside of the shroud were conceived as a means of accomplishing this result since they are outside the slipstream for normal hovering flight and come into play as the slipstream begins to spread out radially from the shroud as the trailing edge of the shroud nears the ground. The angle of these vanes was set to balance out the torque exactly when the model was still on the ground prior to taking off. With this setup the model was able to take off with no appreciable rolling.

The use of sharp-pointed spikes on the landing gear for take-off was tried unsuccessfully as a means of eliminating the effect of the unbalanced torque, rather than eliminating the torque itself. It was thought that if the spikes would prevent the rolling before the model left the ground it might be possible for the model to rise sufficiently fast for the axial antitorque vanes to become effective before the model rolled appreciably. This device was completely unsuccessful, however, since the model began to roll before it actually took off and completed about two revolutions before it could be stopped.

The problem of a change in rolling moment when the aircraft is near the ground would not be expected to occur to any large extent for machines of this general type in which counterrotating propellers are used instead of the single propeller and antitorque vanes.

As shown by the force-test data of figure 7, there was a slight reduction of thrust as the model left the ground. The power operator felt that this reduction in thrust made it easier to take off and stabilize the vertical motion a few feet off the ground.

## Landings

The model could be brought down to a landing on a given spot easily and accurately as indicated by the time histories of figure 8. No trouble was experienced in roll because of variation of rolling moment with height above the ground. In fact, satisfactory landings were made during some preliminary tests when the radial antitorque vanes were not used. These landings were made fairly quickly, however, so that the rolling moment did not have time to make the model roll. The tests without the radial antitorque vanes are brought up mainly because some readers of this paper may have seen a preliminary-data film which showed successful landings in this condition. Actually it is felt that, since the machine could probably not have been hovered continuously near the ground without the radial antitorque vanes (or some such device), the fact that rapid landings can be made without these vanes is mainly of academic interest.

The model experienced a cushioning effect as it neared the ground on landing. If the model were brought down slowly with the power set at only slightly less than hovering power it would stabilize at a slight distance above the ground and would not land unless the power were further reduced. The force-test data of figure 7 give a quantitative indication of the magnitude of this effect. These data show that for a given motor speed the thrust was about 1 pound (3 percent) greater when the landing gear was touching the ground than when the model was far above the ground. In order to make a landing, therefore, the power operator cut the power very sharply as the model neared the ground. Because of this technique and because of the lack of shock absorption in the landing gear, some of the landings shown in figure 8 and in the film supplement appear fairly hard and the ground effect is not evident.

Because of the design of the landing gear, the model often tipped over far enough after the touchdown to bend the radial antitorque vanes. Since the landing gear had a fairly narrow tread and since none of the landing-gear tips would slide across the floor very easily, the model was particularly susceptible to tipping if it touched down with a little sideways velocity. Another factor in this tendency to tip was that there was no spring or shock absorption in the landing gear. The model therefore tended to tip as a result of bouncing when it hit on only one or two landing-gear legs. The rubber button landing gear tips helped reduce this bouncing but both they and the sharp-pointed tips were particularly bad about tripping the model if it touched down with a sideways velocity. Because of the location of the radial antitorque vanes outside of the landing gear and very close to the ground, they were particularly susceptible to damage when the model tipped a little. It is evident that the design of the landing gear for a stand-on type of vertically rising aircraft is a problem that needs further study.

## Forward Flight

The model could be flown fairly smoothly and easily in forward flight. A time history of a flight in which the forward speed was slowly increased from about 0 to 50 miles per hour is shown in figure 9. This flight record does not cover the entire flight since the film in the camera was expended before the flight was terminated. The speed of 50 miles per hour reached in this flight represents a speed of about 80 miles per hour for a full-scale vehicle of this type.

The model seemed to be about neutrally stable, or perhaps slightly unstable, in either angle of attack or airspeed. It would not fly at any speed covered in the tests for more than a few seconds without the use of some elevator control. During the brief test period the pilot was unable to determine whether the instability was the result of an unstable variation of pitching moment with angle of attack or with speed.

It seemed, however, that the model must have had one of these forms of instability to a slight degree. It also had about neutral stick-position stability. The elevator angle varied progressively from $0^{\circ}$ for hovering flight to only $4^{\circ}$ down for a speed of 50 miles per hour. Despite the apparent lack of stability, it was possible to control the model fairly easily. The vertical motions and forward speed could not be controlled as well as desired, however, because of the inability to pitch the model rapidly. It appeared to the pilot, therefore, that the elevator effectiveness was undesirably low as was the case in hovering flight. The model was apparently directionally stable in forward flight and was easier to fly than in hovering flight. It was especially easy to fly at the low speeds as indicated by figure 9 which shows that very little rudder and elevator control was required at speeds from about 15 to 35 miles per hour. In the high-speed part of the flight range the model was easier to fly than in hovering although the flight record (fig. 9) shows that frequent use of the controls was necessary. In this condition the controls seemed very powerful and the deflections were too great for smooth flight. Frequent use of the controls was therefore required to correct for the roughness caused by a tendency to overcontrol occasionally.

There was a pronounced change in roll trim with speed. Since the air velocity through the shroud increases as forward speed increases the rolling moment provided by the axial antitorque vanes increases so that they more than compensate for the motor torque. In the early part of the forward-flight tests the pilot applied left roll control very frequently, as shown in figure 9. With the self-trimming type control actuators used on the model, the roll control was being trimmed to the left at the same time. In the latter part of the tests when the speed had become fairly high, practically no roll control was required in forward flight. The model appeared to have stability of roll attitude which probably resulted from the drag of the cable attached to the rearmost of the four tubular members of the safety structure. The behavior of an aircraft of this type in roll would probably be reasonably satisfactory, however, tests with other vertically rising aircraft models have shown that a pronounced instability in roll, if present, will show up despite such a stabilizing effect of the cable.

## SUMMARY OF RESULTS

The results of a free-flight investigation of the stability and control characteristics of a 0.4-scale model of a shrouded-propeller stand-on type of vertically rising aircraft can be summarized as follows:

1. The model could be flown smoothly and fairly easily in hovering flight and could be maneuvered to any desired position despite the fact that it was about neutrally stable and the controls were somewhat weaker than was desired.

2. Take-offs could be made very easily and landings on a given spot could be made accurately.

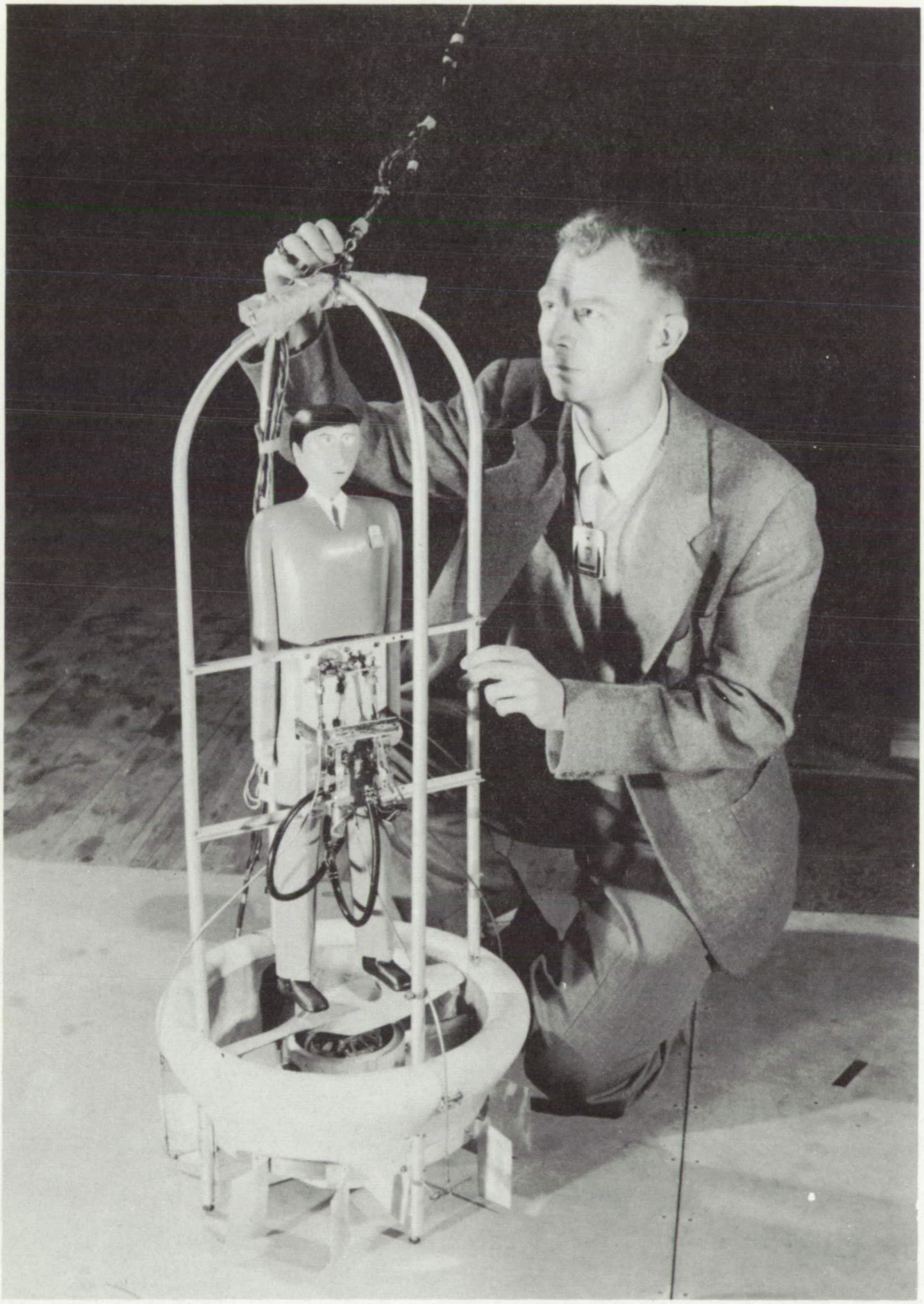
3. The model could be flown fairly smoothly and easily in forward flight at speeds from 0 to 50 miles per hour although the elevator effectiveness was somewhat less than was desired.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 3, 1954.

REFERENCES

1. Zimmerman, C. H., Hill, Paul R., and Kennedy, T. L.: Preliminary Experimental Investigation of the Flight of a Person Supported by a Jet Thrust Device Attached to His Feet. NACA RM L53D10, 1953.

2. Platt, Robert J., Jr.: Static Tests of a Shrouded and an Unshrouded Propeller. NACA RM L7H25, 1948.



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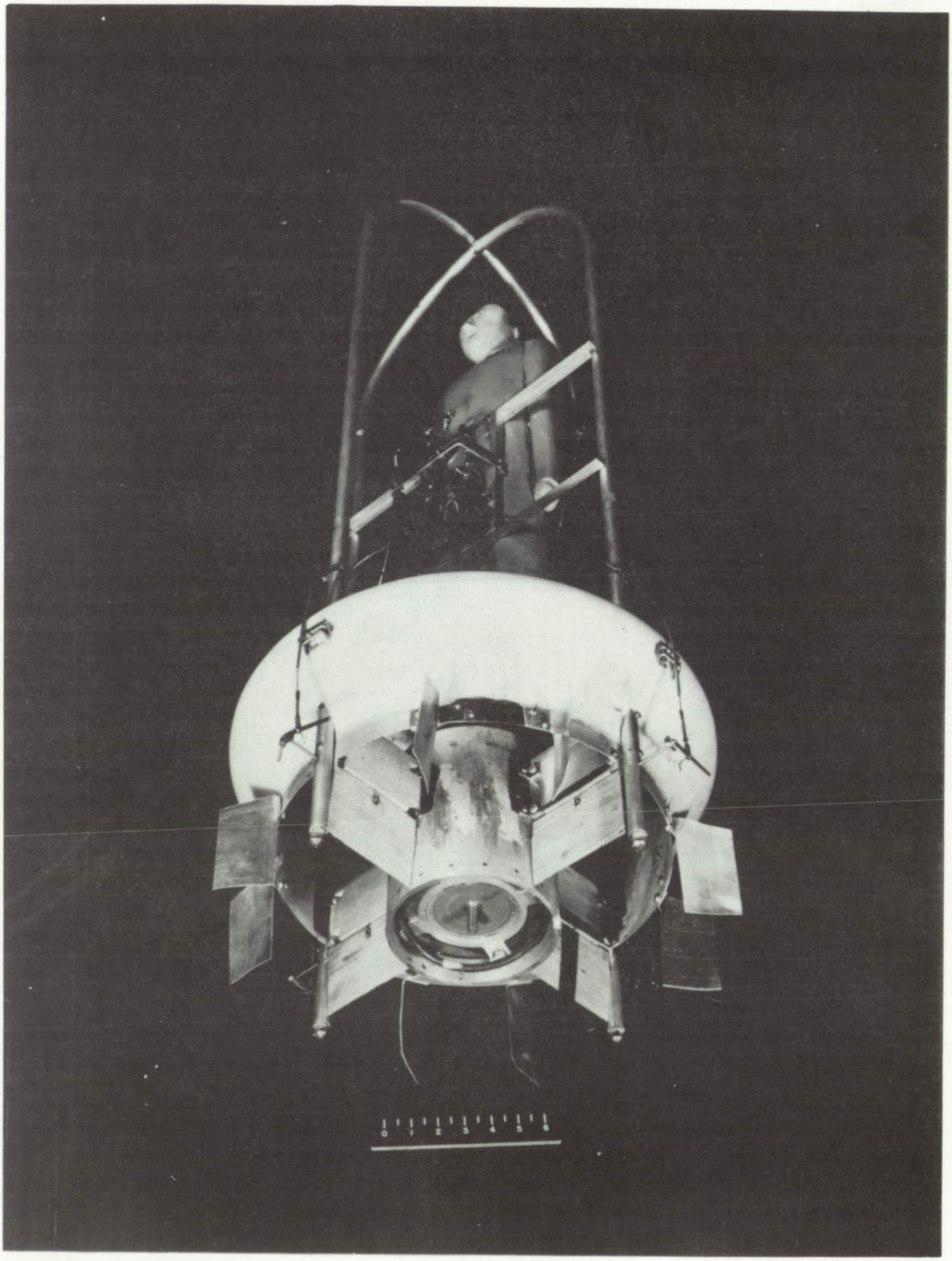
(a) Top quarter view.

Figure 1.- Photographs of the model.

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(b) Bottom quarter view.

Figure 1.- Continued.

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(c) Model in flight.

Figure 1.- Concluded.

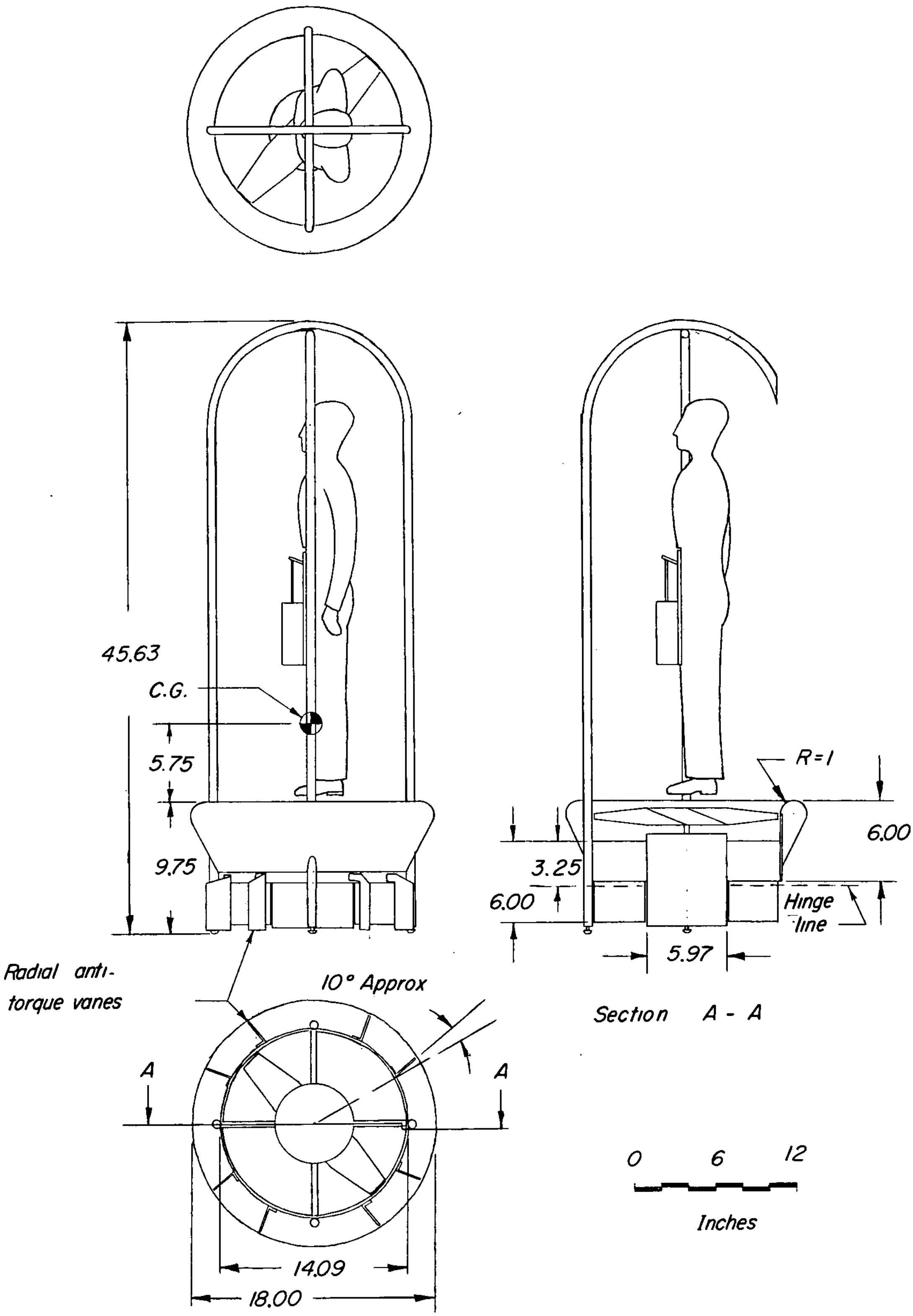


Figure 2.- Drawing of the model. All dimensions are in inches.

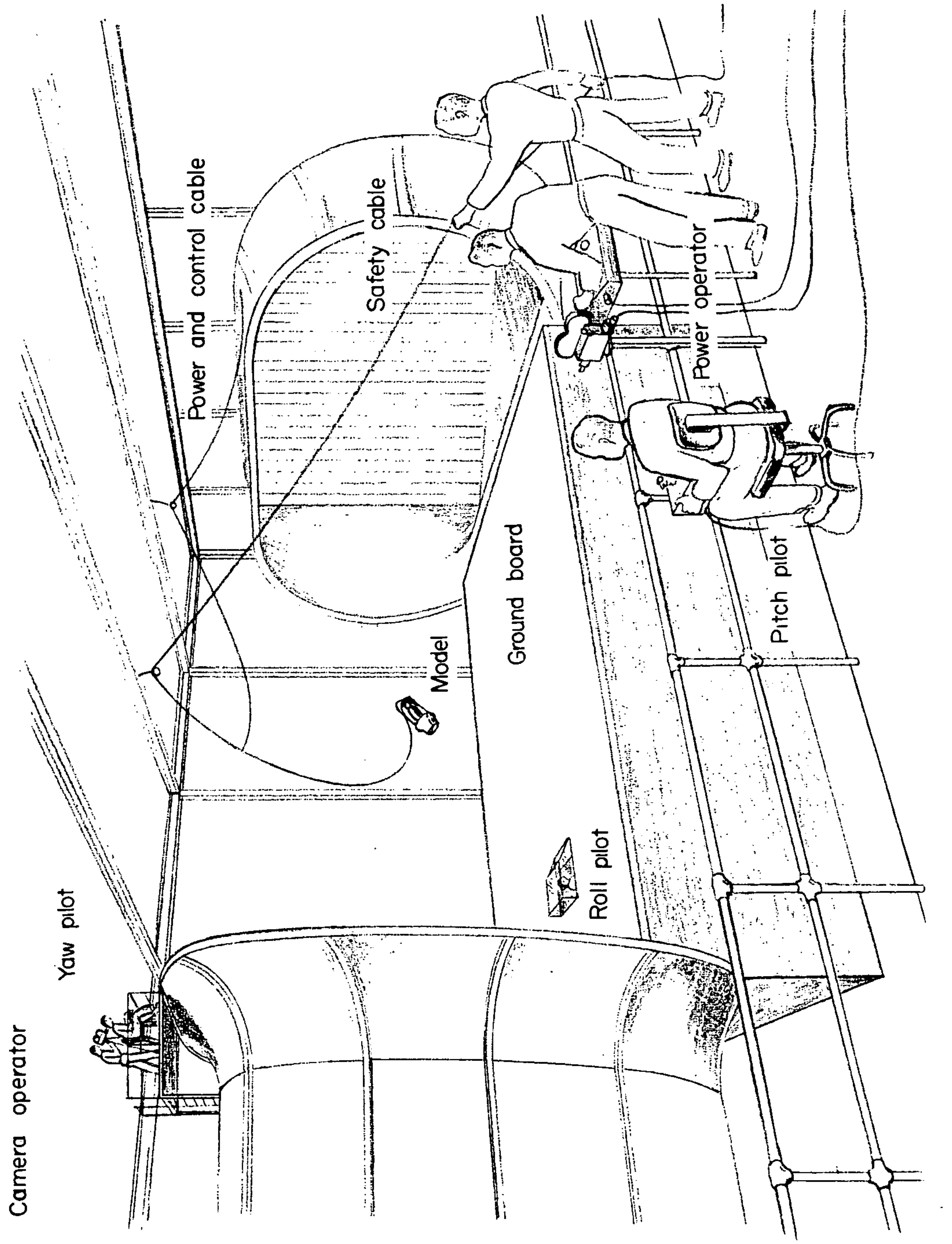


Figure 3.- Sketch of test setup for forward flight tests.

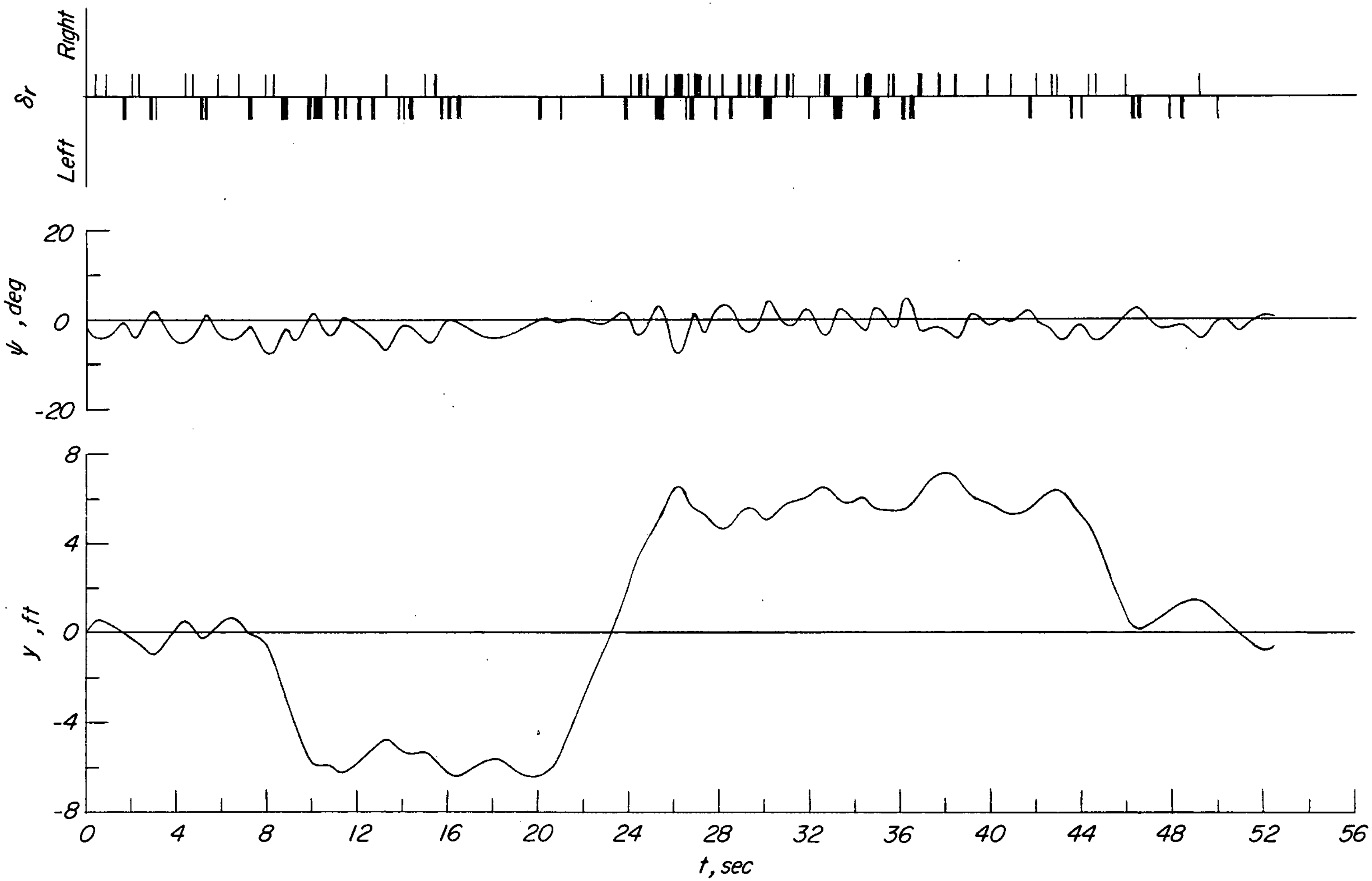


Figure 4.- Time history of the controlled yawing motions in the hovering condition showing the ability of the pilot to fly steadily and maneuver quickly from one position to another.

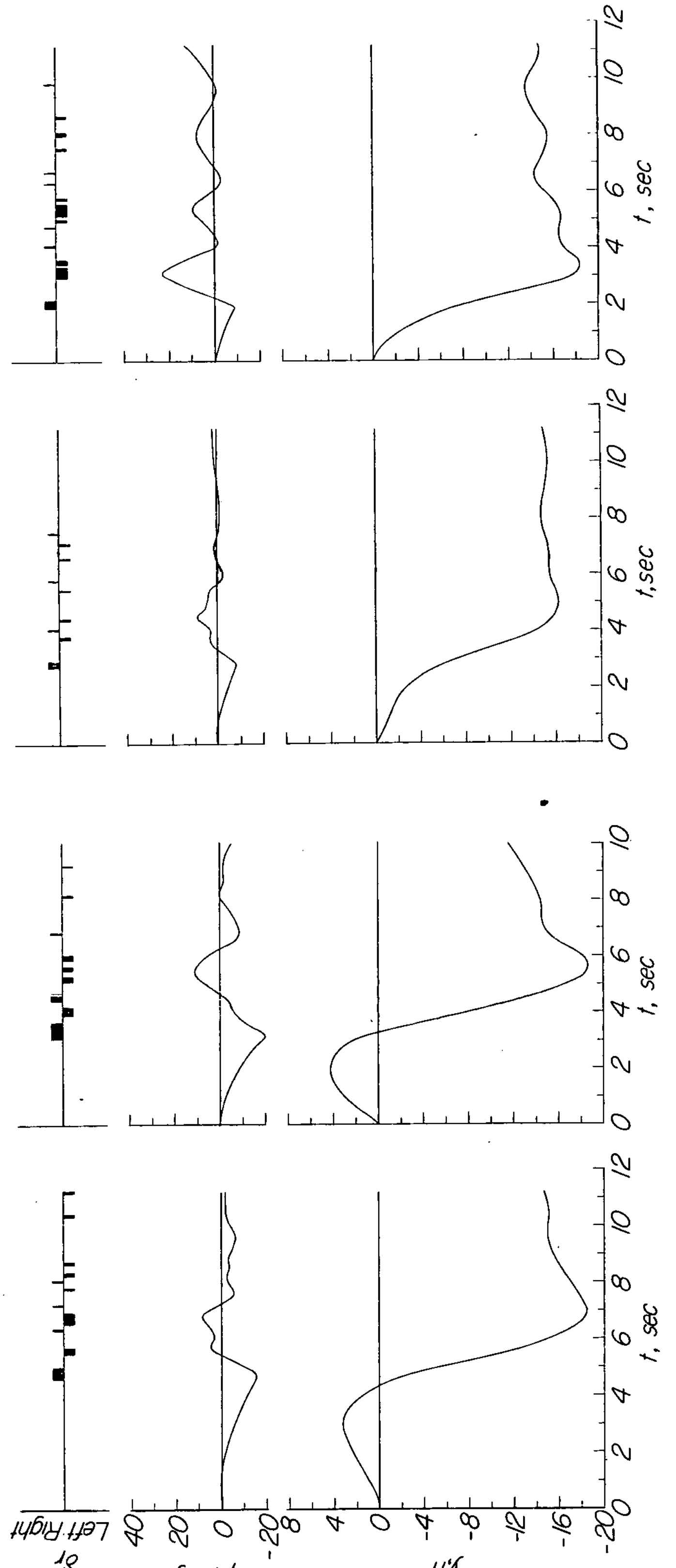


Figure 5.- Time histories showing the ability of the pilot to stop the uncontrolled yawing motions after they had been allowed to build up.

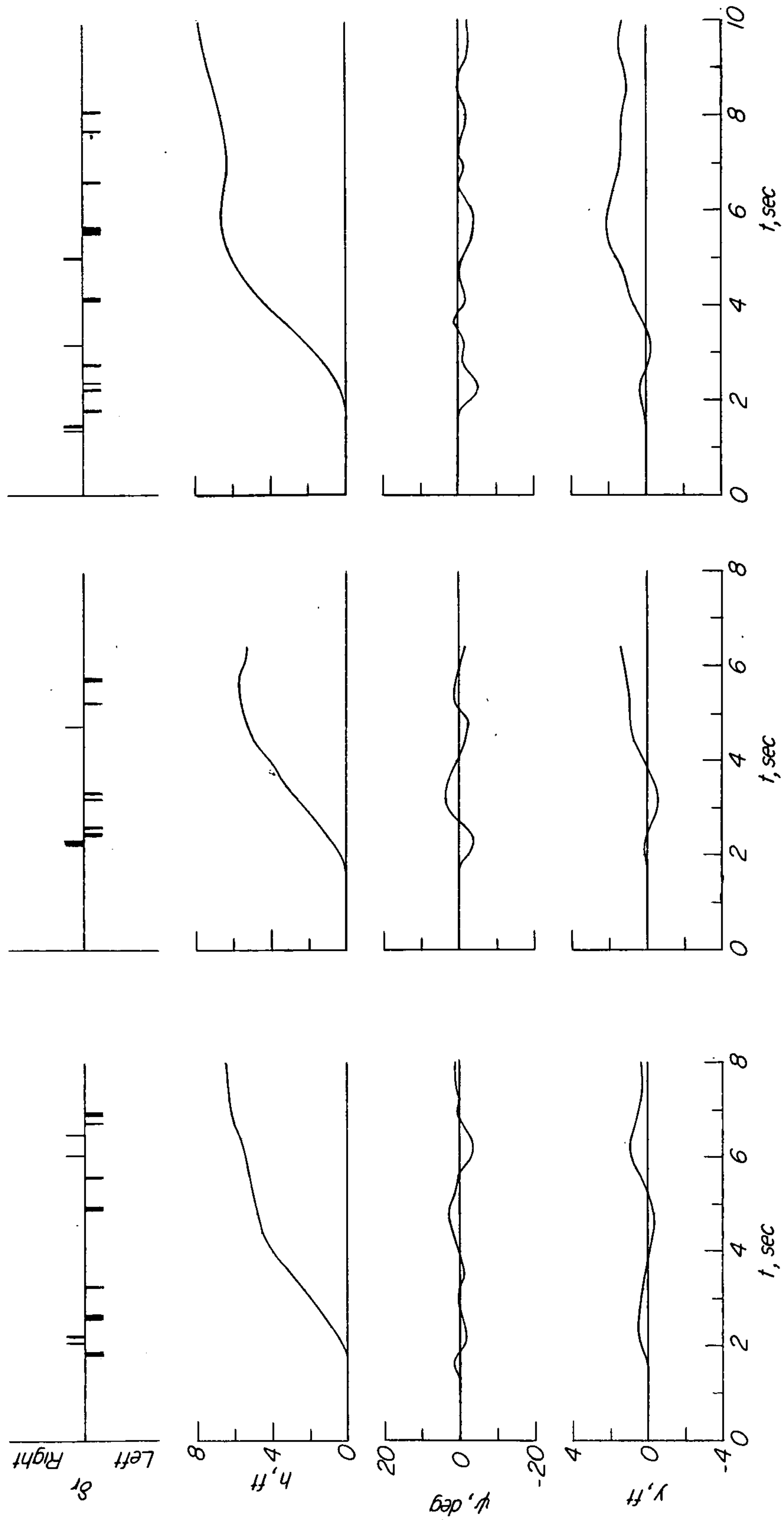


Figure 6.- Time histories of the motions of the model during take-offs.

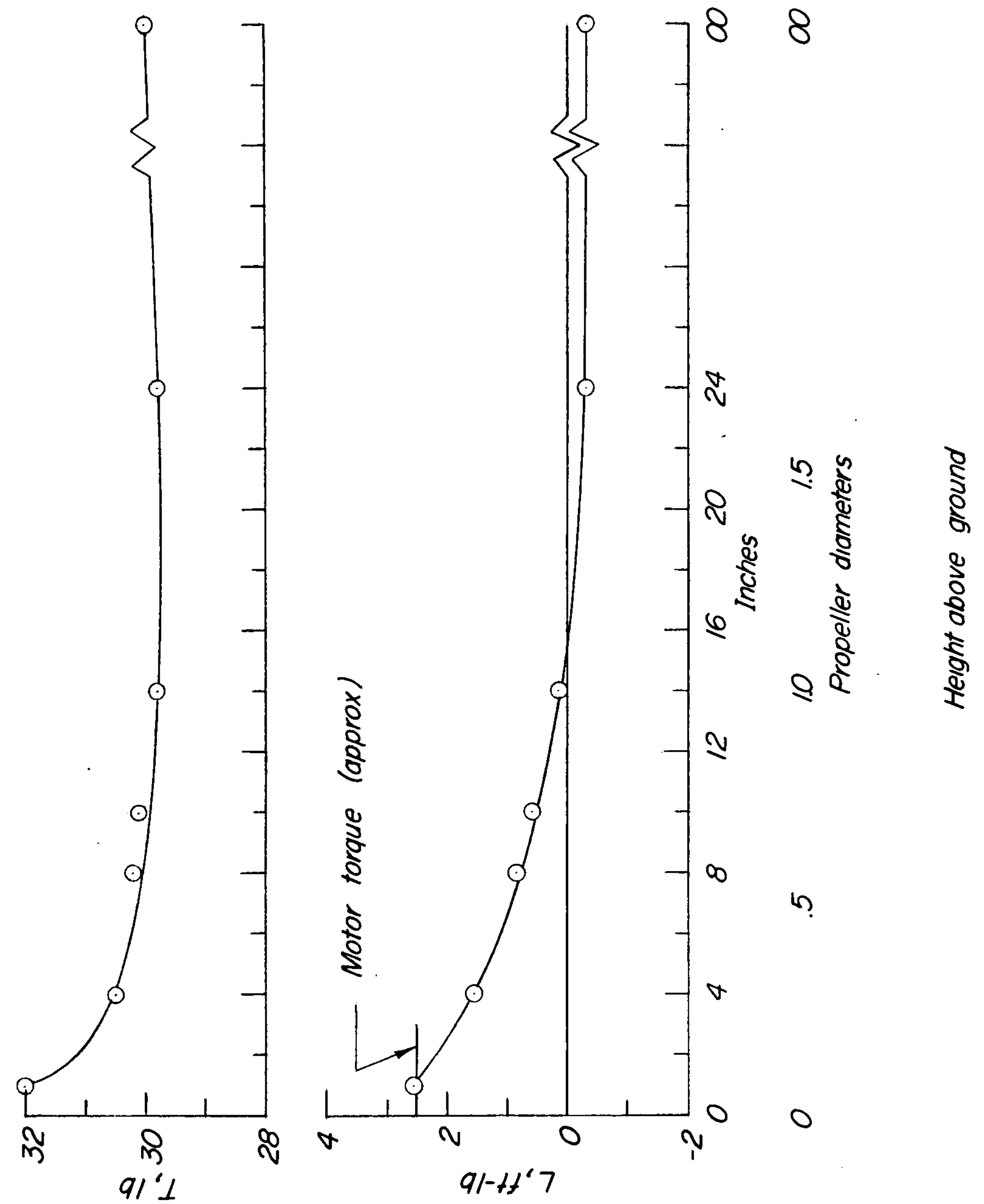


Figure 7.- Force test results showing the variation of thrust and rolling moment with height of the trailing edge of the shroud above the ground for the hovering flight condition of a similar model.

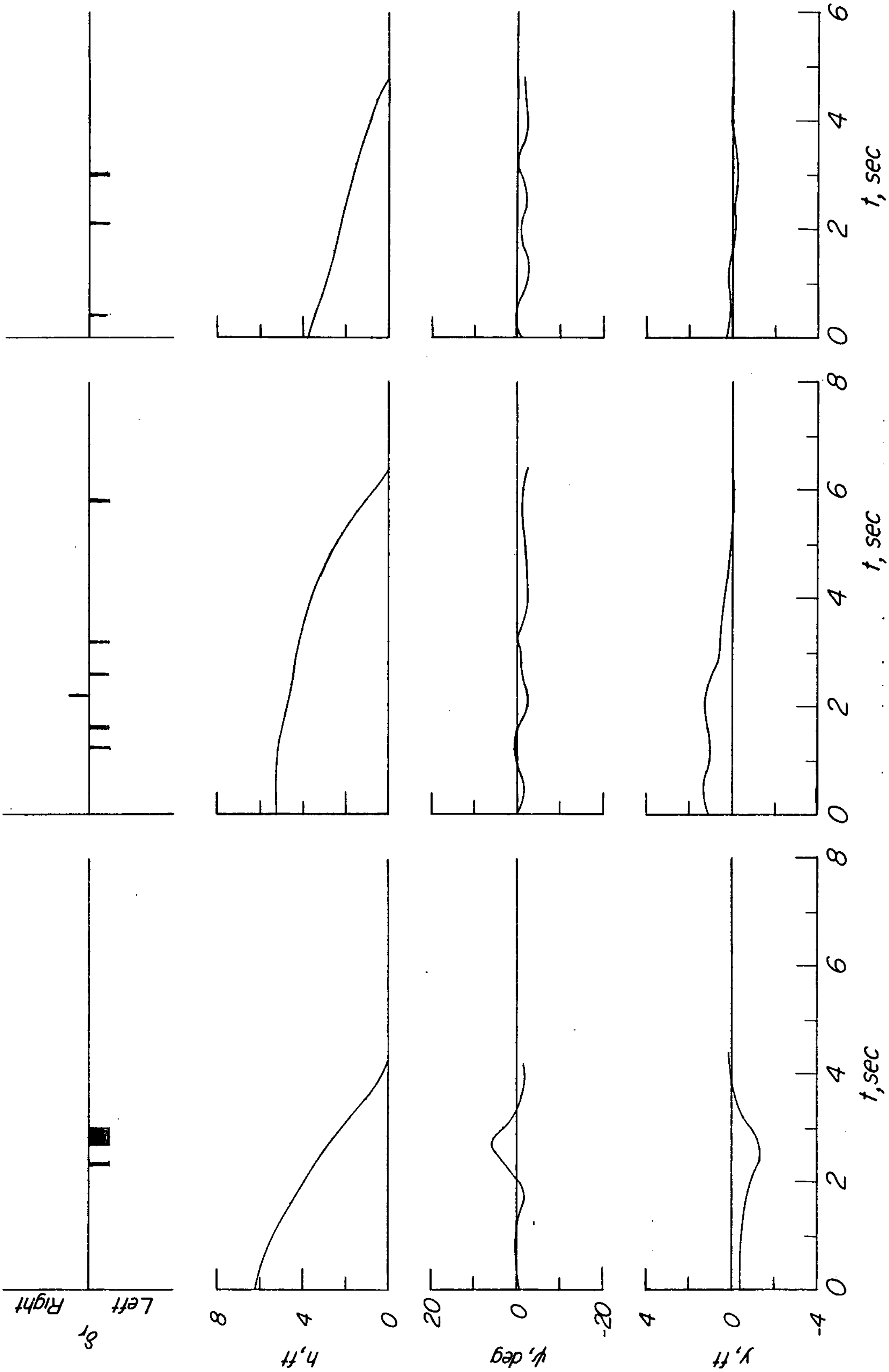


Figure 8.- Time histories of the motions of the model during landings.

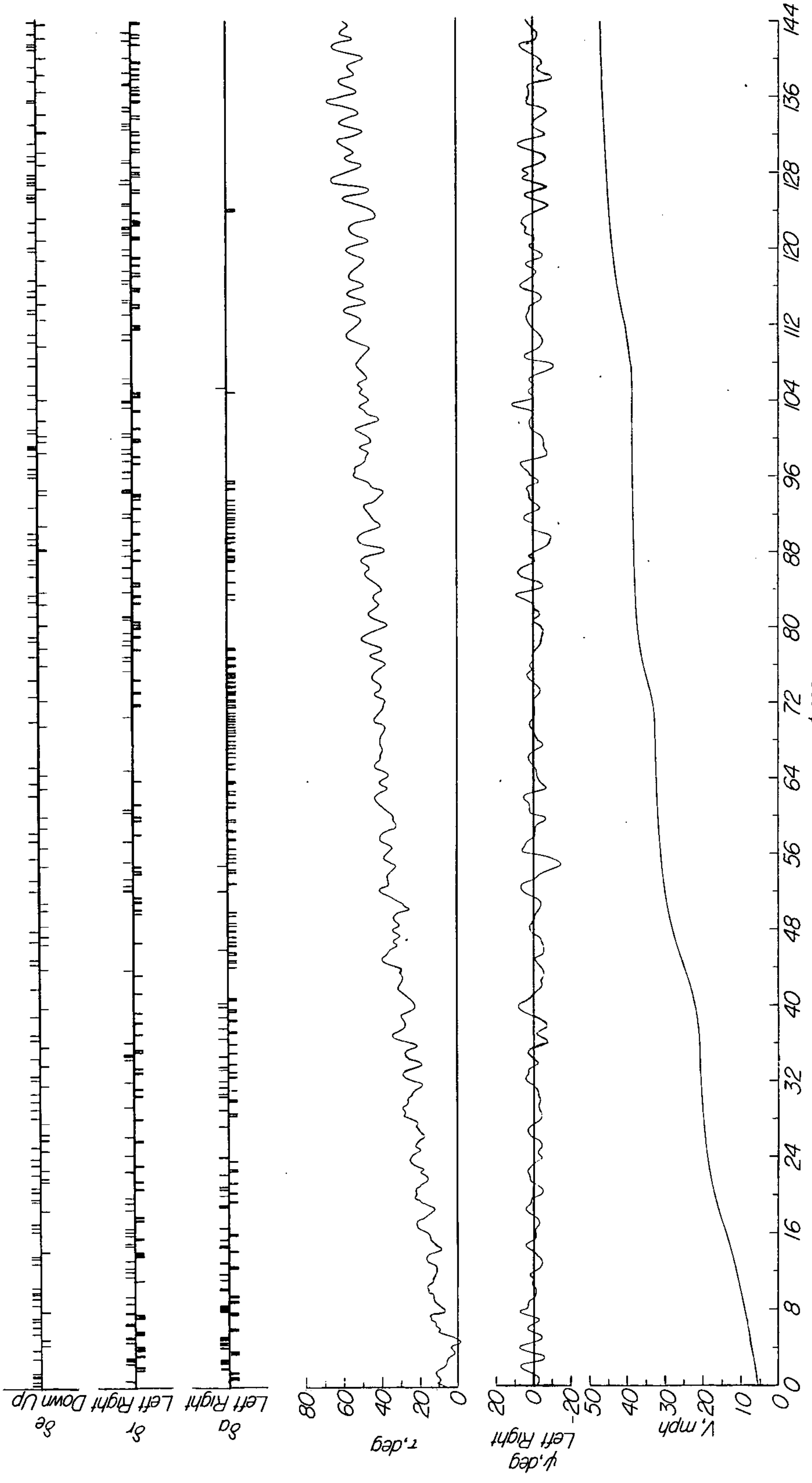


Figure 9.- Time history of the motions of the model in forward flight at speeds from 0 to 50 miles per hour.



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